Mid-Cretaceous Hawaiian rocks in Kamchatka

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Scientists from IFM-GEOMAR found geochemical evidence for preservation of ~100 m.y. old Hawaiian hotspot rocks in Kamchatka (Far-East of Russia). New trace element and isotope data show that the Hawaiian mantle plume is very persistent in composition during millions of years and originates from a large chemically isolated mantle domain at the Earth core-lower mantle boundary.

The Hawaiian-Emperor Seamount Chain, produced during the passage of the Pacific Plate over the Hawaiian hotspot, extends for 5800 km from the currently active island of Hawaii and Loihi Seamount northwest to the Detroit and Meiji seamounts, seaward of the Kamchatka-Aleutian arc junction (Fig. 1). Despite the extensive data set on the composition and evolution of the Cenozoic Hawaiian magmatism, there is little known about the earlier (>80 m.y.) history of the hotspot. Several studies have proposed that an igneous plateau formed by the plume head at the initiation of the Hawaiian hotspot and that older seamounts formed above the plume tail may have been preserved along the Aleutian Arc, in the Bering Sea or in Kamchatka rather than subducted. There was however no convincing geochemical data which support preservation of older Hawaiian fragments on land or on the sea floor.

During several years scientists from the IFM-GEOMAR together with their Russian colleagues from the Institute of Volcanology and Seismology in Petropavlovsk–Kamchatsky studied geologic structure and composition of rocks preserved in the southwestern part of the Kamchatsky Mys Peninsula (Eastern Kamchatka) (Fig. 1), which consists of ophiolite association of ultramafic rocks, gabbros, dolerites, basalts and sediments of the Late Cretaceous-Eocene age.
Volcanic rocks in the ophiolites occur in the ~1.5 km thick succession together with hyaloclastites and intercalated red jasper and pink pelitomorphic limestone, consistently dated paleontologically as Albian-Cenomanian (120-93 m.y.).
Volcanic rocks in the ophiolite association range from trace-element-depleted to slightly enriched mid-ocean-ridge-like basalts (MORB-like) to alkali basalts suggesting that this magmatic assemblage is characteristic of plume-type ophiolites originating from plume-related oceanic ridges and plateaus.

A novel result of the detailed geochemical investigations of the ophiolite rocks, reported in a paper published by Geology in 2008 (Portnyagin et al., 2008) was recognition of a distinctive group of the ophiolite basalts, trace-element-enriched tholeiites cropping out in the northern part of the massif. The rocks are altered olivine-

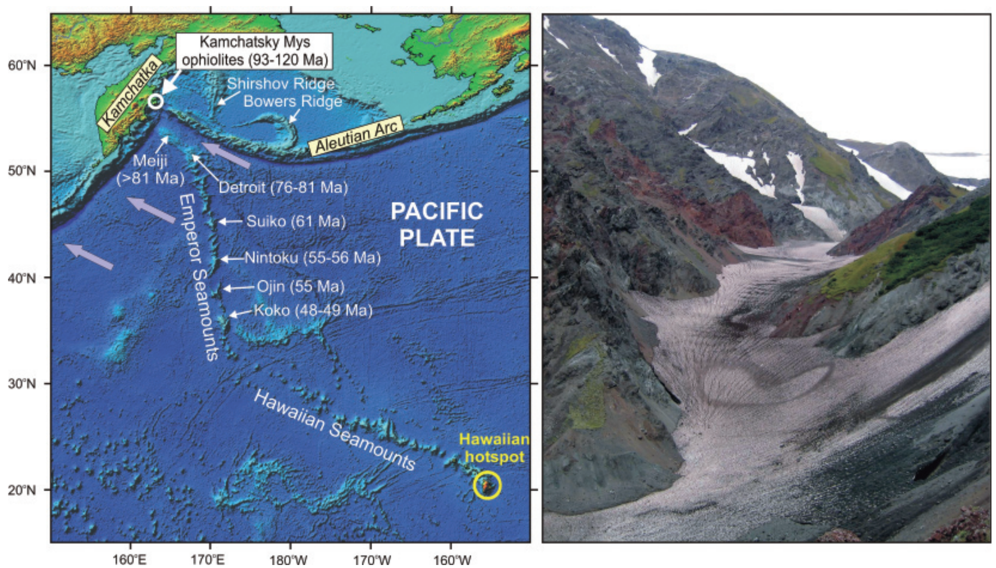
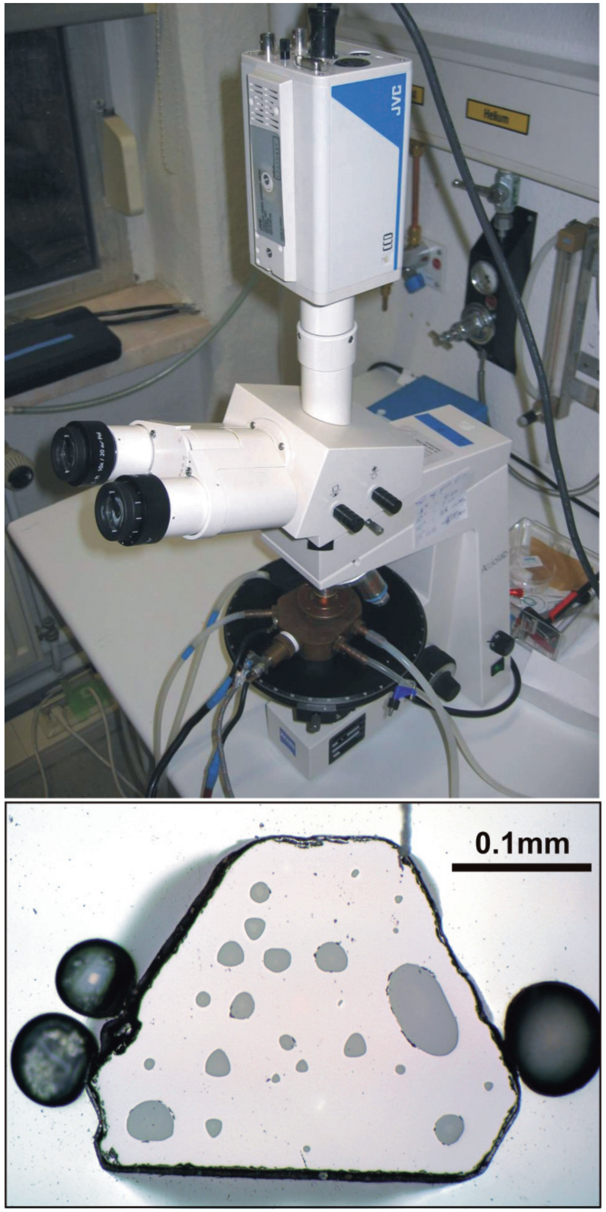


Figure 1. The Hawaiian-Emperor Seamount Chain in the northwestern Pacific, produced by the passage of the Pacific Plate of variable age and thickness over the Hawaiian hotspot, and the position of the Kamchatsky Mys ophiolite complex are shown on the left panel (modified after Portnyagin et al., 2008). Photograph in the right panel illustrates outcrops of oceanic pillow-lavas in the Kamchatsky Mys Peninsula (Photo by Dmitri Savelyev).



phyric basalts with very peculiar enriched patterns of incompatible trace elements, Nd and Pb isotope compositions differing from Mesozoic Pacific MORB but falling completely within the compositional range of samples from Detroit Seamount (DSDP Site 1203) belonging to the Hawaiian hotspot track.

In order to collect additional information on the composition of parental magmas of the Kamchatka basalts, this study was extended to include a detailed examination of a mineral chromium spinel (solid solution of Mg, Al, Cr and Fe oxides) in the rocks. Many spinel crystals were found to contain partly crystallized inclusions of 10 to 70 micron in size (Fig. 2), which represent microscopic droplets of melt trapped by spinel during its growth in magma and recrystallized when the magma cooled down. The rocks were hydrothermally altered on the post-magmatic stage. The inclusions inside spinel, a mineral particularly resistant to post-magmatic alteration, remained isolated from the rock matrix by the host mineral and thus preserved information about initial magma composition.

To eliminate effects of crystallization on melt inclusion composition, spinel crystals with inclusions were placed at the temperature of their origin (1250 °C) using the Vernadsky-type stage for high-temperature experiments at the IFM-GEOMAR (Fig. 2). At this temperature crystal phases inside inclusions melted out. Quenched glasses of the melt

Figure 2 (left column). Vernadsky-type stage for high-temperature experiments under microscope at the IFM-GEOMAR used to homogenize melt inclusions in this study (upper panel) and micrograph of melt inclusions in spinel crystal from the Kamchatka ophiolite basalt after experiment (lower panel).

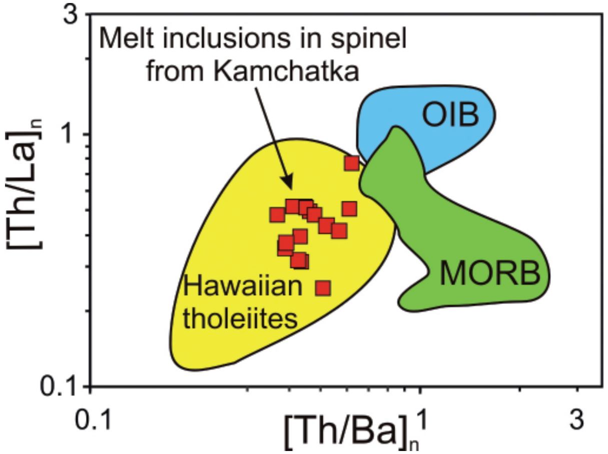


Figure 3. Melt inclusions in spinel from the Kamchatsky Mys ophiolites have Hawaiian-type Th/Ba and Th/La ratios, which are systematically lower compared to the majority of ocean island basalts (OIB) and mid-ocean ridge basalts (MORB). (modified after Portnyagin et al., 2008)

inclusions were analyzed by electron probe and secondary-ion mass-spectrometry for major and many trace elements. These analyses showed that all studied melt inclusions had very low Th/La and Th/Ba and high Nb/La ratios, which are very similar to that of the Hawaiian hotspot lavas and melt inclusions but were not documented for mid-ocean ridge and ocean island basalts from other localities (Fig. 3).

On the basis of these geochemical data the ophiolite basalts were suggested to very likely derive from a Hawaiian-type mantle source, and thus evidence for the existence of the Hawaiian hotspot 120-93 m.y. ago. The studied rocks occur as lava flows in association with slow-accumulated deep-sea sediments (intercalated cherts and limestones) and hyaloclastites. The lavas

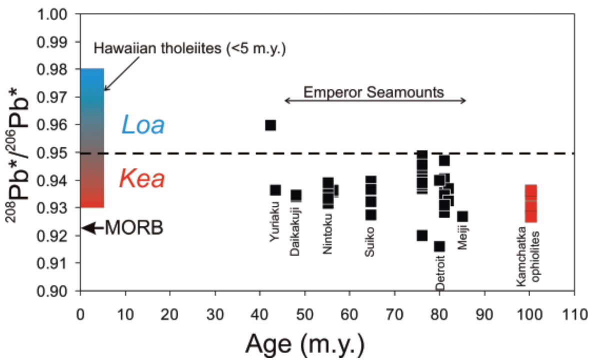


Figure 4. Lead isotope compositions of the Emperor Seamount Chain rocks and enriched tholeiites from the Kamchatsky Mys ophiolites indicate prevailing contribution from "Kea" mantle component ($^{208}Pb^{*}/^{206}Pb^{*}$ <0.95) similar to that in rocks of Mauna Kea volcano. "Loa" component ($^{208}Pb^{*}/^{206}Pb^{*}$ >0.95) is not common in the Hawaiian hotspot rocks older than 5 m.y. old (modified after Portnyagin et al., 2008). The ratio $^{206}Pb^{*}/^{208}Pb^{*}$ represents time-integrated $^{232}Th/^{238}U$ ratio since the formation of the Earth.

could thus have originated on the deep flank of a seamount or on a mid-ocean ridge, strongly affected by interaction with the neighbouring Hawaiian hotspot.

Low Th/Ba ratios in Hawaiian hotspot lavas and studied Kamchatkan melts deviate strongly from typical mantle values and can be explained by melting of low-Th recycled crustal material within the plume source. As evident from the published data and results from this study, a contribution from the low-Th recycled material to the Hawaiian hotspot-derived magmas was persistent over the last ~100 m.y. Moreover, low $^{206}Pb^{*}/^{208}Pb^{*}<0.95$ in the least altered Emperor Ridge rocks and lavas from the Kamchatka forearc studied here (Fig. 4) and also unusually high Nb/La in the melt inclusions, similar to inclusions from Mauna Kea lavas, suggest that it was probably Kea-type component, which contributed, together with a depleted plume component to prevailing compositions of Cretaceous Hawaiian hotspot lavas.

A persistent yet heterogeneous composition of Hawaiian hotspot lavas suggests that their source region represents a long-lived prominent geochemical anomaly in the Earth's mantle. Assuming that the volume flux of the Hawaiian plume was similar from the mid-Cretaceous to the present (300 m^3/s) and that the plume originates at the core-mantle boundary, the source region of the Hawaiian plume over the last ~100 m.y. was estimated to cover an area of ≥15% of the core-mantle boundary in the form of a ≤40 km thick layer. Long-lived (≥20 m.y.), complex spatial zonation has also been shown for the Galapagos hotspot and thus also requires a volumetric large-scale geochemical anomaly in the Earth's mantle, which may be an important feature of plume-related hotspot volcanism.

In summary, this work provides evidence that older (than preserved on the NW Pacific seafloor) products of the Hawaiian hotspot have been accreted to the fore-arc of the Kamchatka subduction zone. This study has important implications for the persistence of chemical characteristics of hotspots over ~100 m.y. and the spatial scale of the compositional heterogeneity in the Earth's mantle. This research was supported by the Deutsche Forschungsgemeinschaft (HO1833/14-1) and the Bundesministerium für Bildung und Forschung (KALMAR project). The study of longevity and geochemical evolution of the Hawaiian hotspot is to be continued in the IFM-GEOMAR on the Phase 2 of the KALMAR project focused on the Shirshov and Bowers Ridges in the Bering Sea, possible fragments of the Hawaiian hotspot track.

Reference:

Portnyagin M.V., Savelyev D.P., Hoernle K., Hauff F., Garbe-Schönberg D., 2008: Mid-Cretaceous Hawaiian tholeiites preserved in Kamchatka. *Geology*, **36**(11), 903-906, doi: 910.1130/G25171A.25171.